



through September. It needs to be pointed out again that the above chemical patterns are based on only two monitoring stations.

6.4.4.2 Urban Aerosols in the Upper Midwest

The agricultural upper Midwest (Figure 6-42b) shows the smallest decline in PM_{10} concentrations among the regions. In the upper midwestern U.S. there was a decrease in the annual average PM_{10} concentration between 1988 and 1994 from $30 \mu g/m^3$ to $25 \mu g/m^3$ for all sites and from $32 \mu g/m^3$ to $26 \mu g/m^3$ for trend sites (Figure 6-42b). The reductions were 17% for all sites and 19% for trend sites. As over the eastern U.S., the highest concentrations occur in the vicinity of urban areas. Some of the station-to-station concentration spread arises from low concentrations over western North Dakota. On the average, the deviation among the stations over the region is a moderate 30% (Figure 6-39). The upper Midwest is also unique in that it shows the regionally lowest seasonal amplitude of 19%, with the slightly lower concentrations occurring in December and January. The sparse size segregated data indicate that only 38% of PM_{10} is contributed by fine particles. This is an indication that coarse wind blown dust from natural or man-induced sources prevails. In this sense, the region is similar to the Southwest (see below).

The daily regionally averaged PM_{10} concentrations in the upper Midwest (Figure 6-43) range between 14 and $45 \mu g/m^3$. The highest values ($>40 \mu g/m^3$) generally occur in the summer season, while the low regional concentrations occur mainly in the cold season, but low values also occur in the summer. It is interesting that the lowest PM_{10} concentrations over the upper Midwest ($15 \mu g/m^3$) are comparable to the Southeast and the industrial Midwest, but differ from these regions by the absence of immediately subsequent high concentration events or episodes. In fact, the PM_{10} “episodes” over the upper Midwest are all in the 40 to $45 \mu g/m^3$ concentration range, compared to 50 to $75 \mu g/m^3$ in the Midwest. The seasonality is barely discernible from the time series confirming that the day to day variation exceeds the seasonal modulation. The urban excess PM_{10} (AIRS-IMPROVE) for the upper midwest is given in Figure 6-44, but its reliability may be in question because of the very small number of nonurban sites.

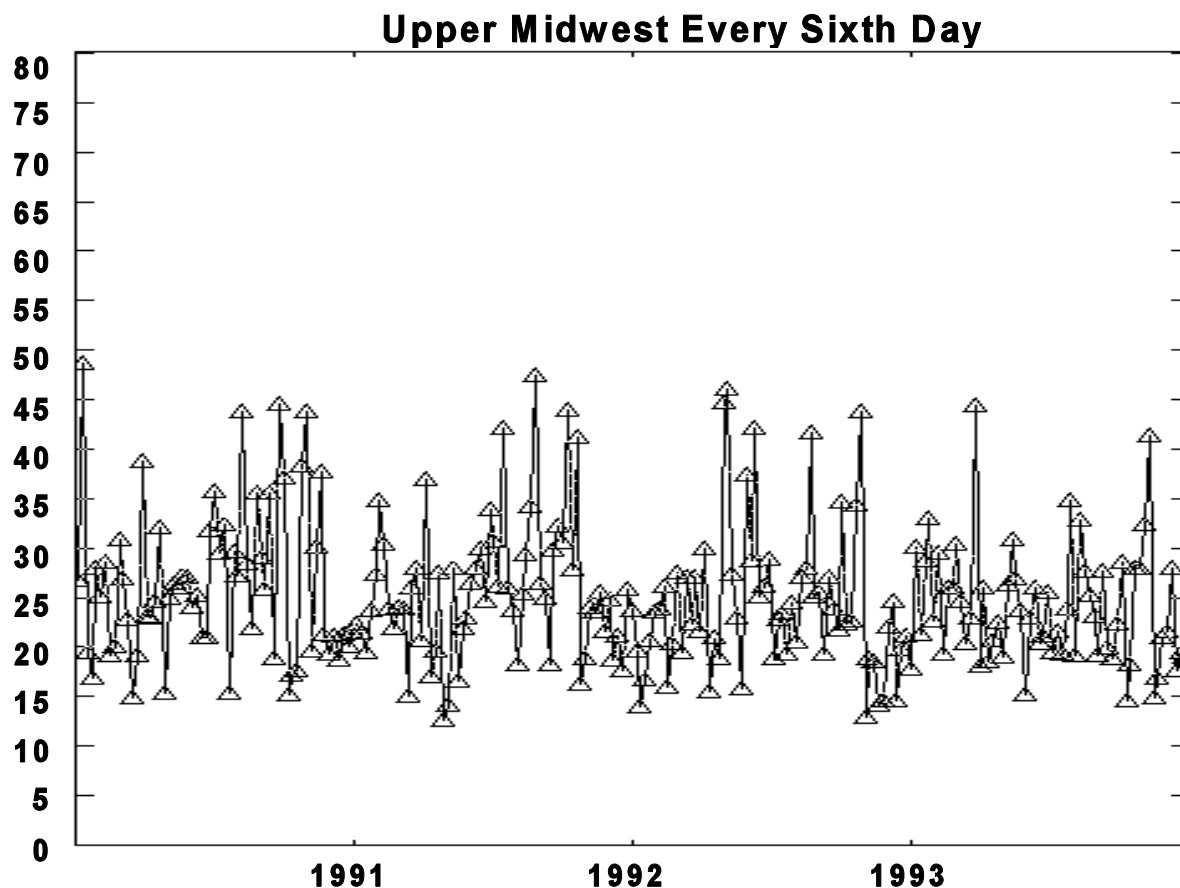


Figure 6-43. Short-term variation of PM₁₀ average for the Upper Midwest. Data are reported every sixth day.

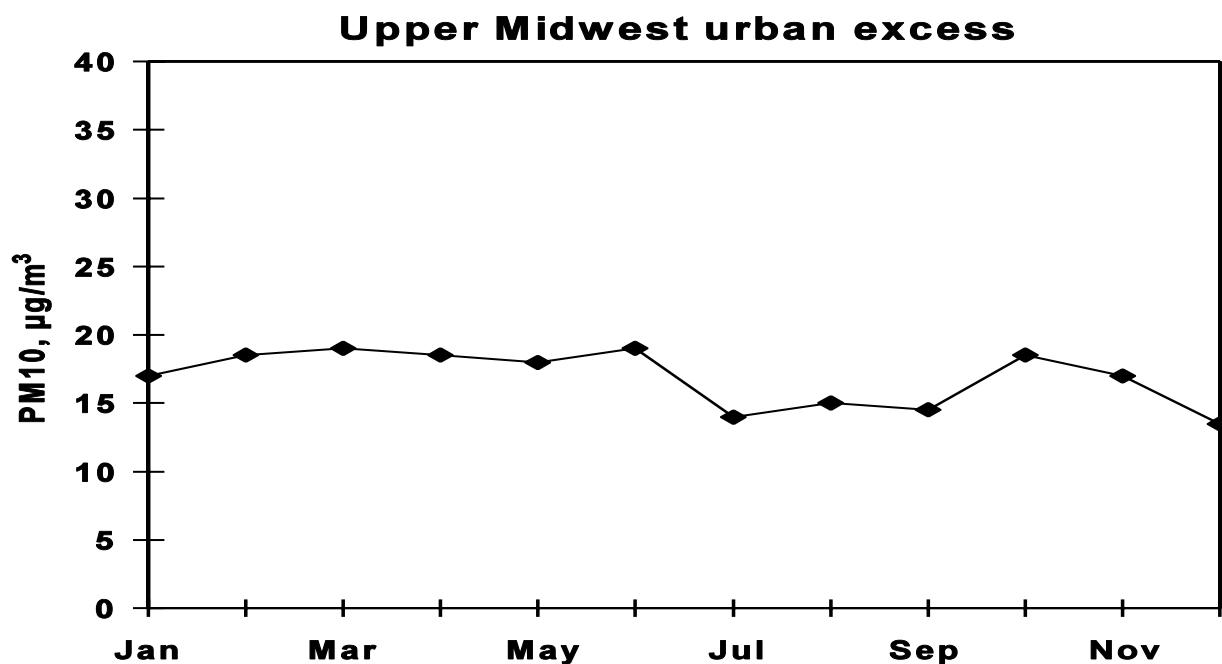


Figure 6-44. Urban excess concentration (AIRS minus IMPROVE) for the Upper Midwest.

6.4.5 Regional Aerosol Pattern in the Southwest

The Southwest covers the arid states from western Texas to Arizona (Figure 6-45a). The Southwest is characterized by mountainous terrain features between the southern Rockies and the Colorado Plateau. The industrial activity and agriculture is minor compared to other regions. Major population centers include El Paso, Phoenix, and Tucson. The meteorology of the region is characterized by low annual precipitation, except during the periods when moist air penetrates from the Gulf of Mexico toward these states, bringing moisture and precipitation.

6.4.5.1 Nonurban Size and Chemical Composition in the Southwest

The PM_{10} concentrations at nonurban southwestern sites show a double peak, one during the late spring (April through July), and another in October. This bimodal seasonality is imposed by the coarse particle mode. The $PM_{2.5}$ mass concentration is unimodal with a summer maximum. Overall, the nonurban PM_{10} concentrations are comparatively low (8 to $15 \mu\text{g}/\text{m}^3$) and over 60% contributed by coarse particles (Figure 6-45b).

The chemical mass balance (Figure 6-45c) shows sulfates to be the larger contributor during the winter (December through March) as well as in late summer (July through October). However, sulfate and organic carbon contributions are comparable during March through June as well as during November through December. Fine particle soil plays a prominent role in the spring fine particle chemical mass balance reaching 25%, but the contribution of soil decreases during the summer, and during December through February dwindles to below 10%.

The selenium and vanadium concentrations (Figure 6-45d) are very low and rather invariant throughout the year. The fine particle sulfur concentration is low and exhibiting a weak maximum during August. The S/Se ratio is comparatively low and bimodal, with peaks in April through May as well as August through October.

6.4.5.2 Urban Aerosols in the Southwest

In the southwestern U.S. there was a decrease in PM_{10} concentrations between 1988 and 1994 from $38 \mu\text{g}/\text{m}^3$ to $24 \mu\text{g}/\text{m}^3$ for all sites and from $43 \mu\text{g}/\text{m}^3$ to $29 \mu\text{g}/\text{m}^3$ for trend sites (Figure 6-46b). The reductions were 37% for all sites and 33% for trend sites. The

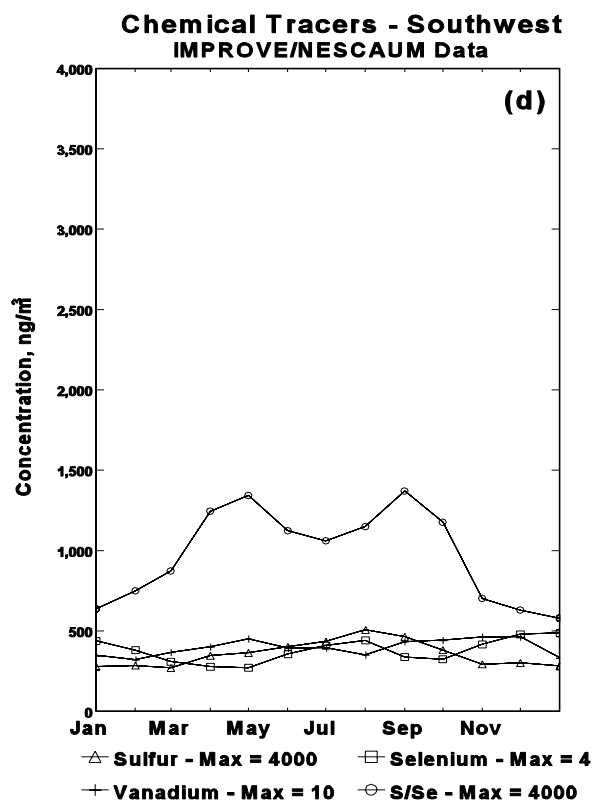
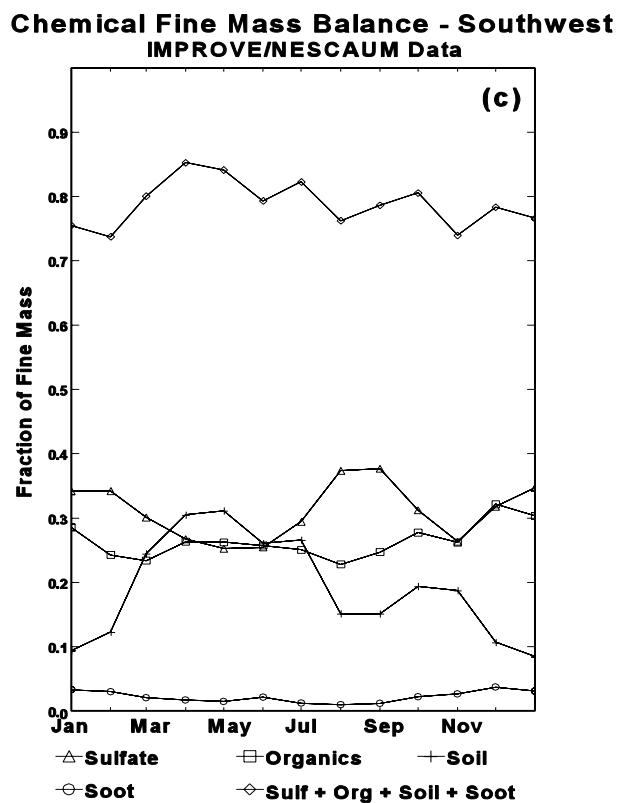
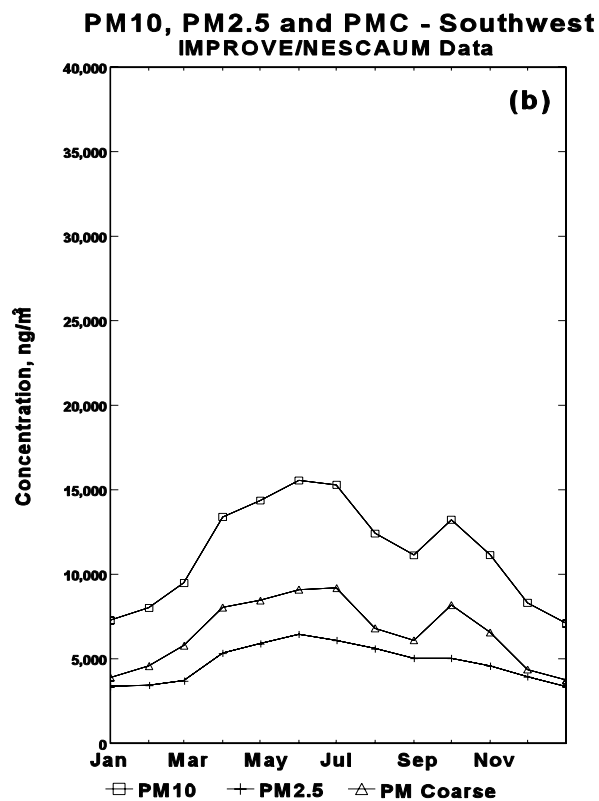
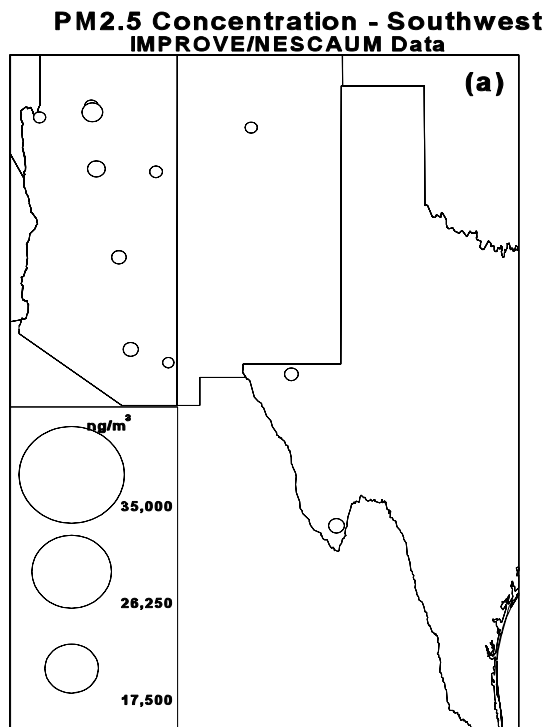


Figure 6-45. IMPROVE/NESCAUM concentration data for the Southwest:
(a) monitoring locations; (b) PM₁₀, PM_{2.5}, and PM_C (PMC); (c) sulfate, soil, organic carbon (OC), and elemental carbon (EC) fractions; and (d) tracers.

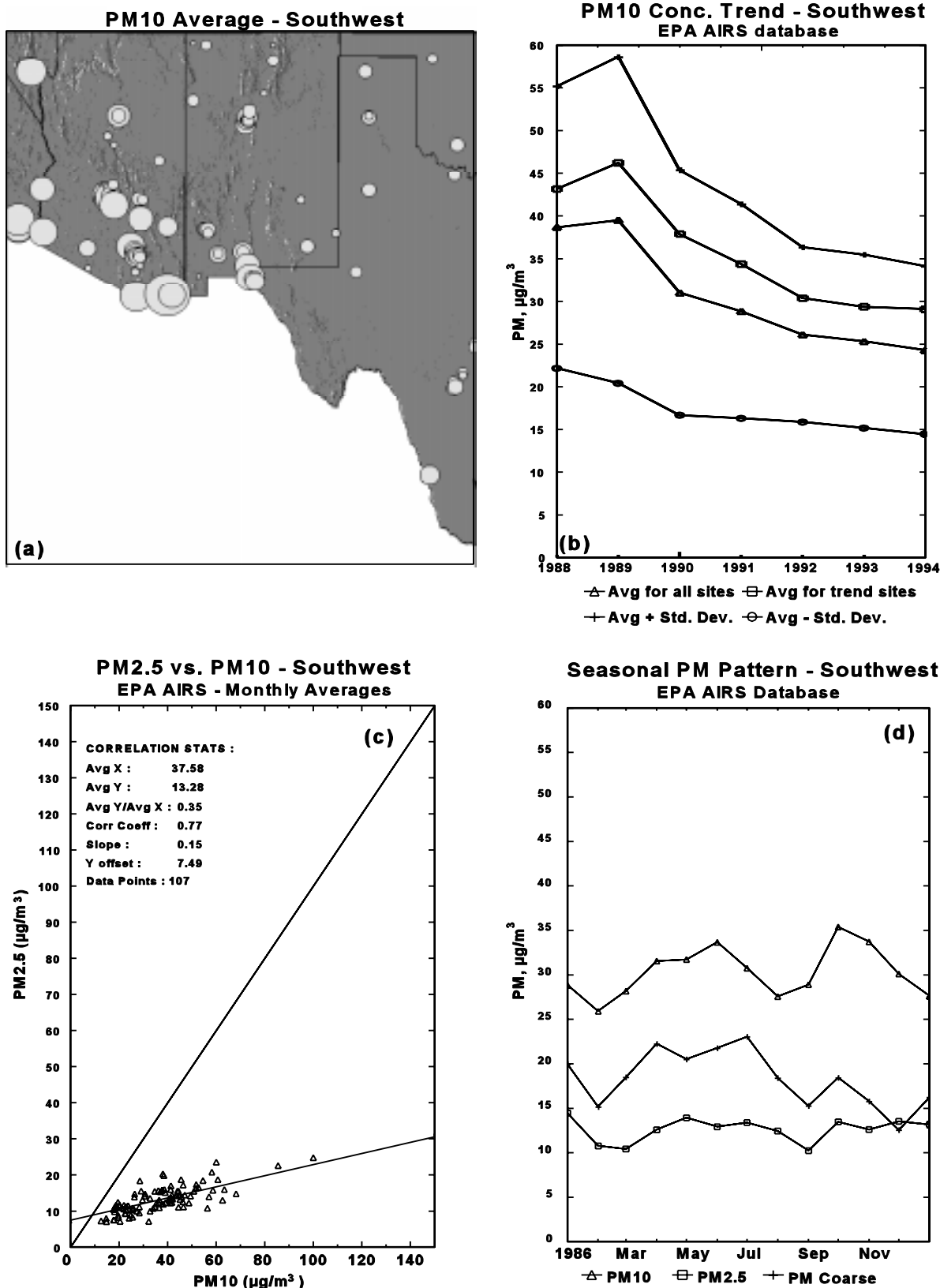


Figure 6-46. AIRS concentration data for the Southwest: (a) monitoring locations; (b) regional PM_{10} monitoring trends; (c) PM_{10} and $PM_{2.5}$ relationship; and (d) PM_{10} , $PM_{2.5}$, and PM_{Coarse} seasonal trends.

downward trends in PM_{10} concentrations were not monotonic. In the Southwest is the large concentration spread of 45% among the monitoring sites (Figure 6-46b). Sites with low concentrations ($<20 \mu\text{g}/\text{m}^3$) occur adjacent to high concentration sites ($>50 \mu\text{g}/\text{m}^3$).

Seasonally, the Southwest PM_{10} concentration shows two peaks, one in late spring April through June, and another during the fall October through November. The concentration dip in August and September has not been observed for any other region. The late summer concentration drop coincides with the occurrence of the moist air flows from the Gulf of Mexico. The size segregated aerosol samples from the Southwest clearly show that coarse particles make the major contribution to the PM_{10} concentration, the fine particles contributing only 37% (Figure 6-46a). The scatter in Figure 6-46c indicates that high PM_{10} concentration months can occur with low concentrations of fine particles. In the Southwest natural and man-induced coarse particle dust is a major contributor to PM_{10} aerosols (Figure 6-45c).

The short term PM_{10} concentration over the Southwest (Figure 6-47) exhibits a highly irregular pattern, that ranges between 11 to $52 \mu\text{g}/\text{m}^3$ regional average. Both the lowest (10 to $15 \mu\text{g}/\text{m}^3$) as well as the highest values are dispersed throughout the year.

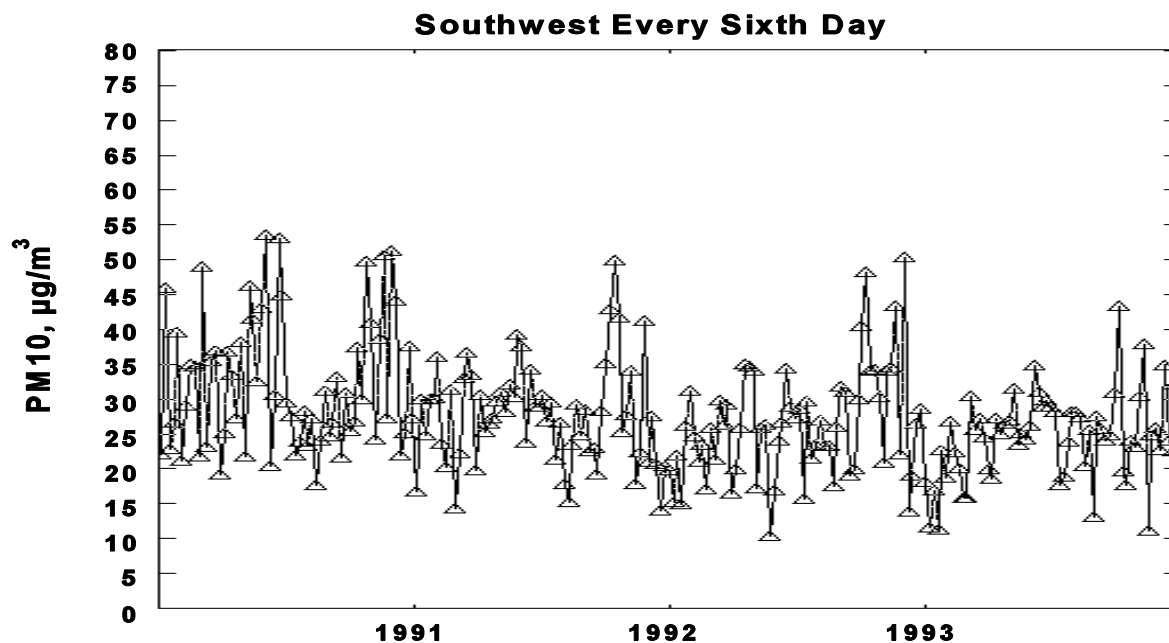


Figure 6-47. Short-term variation of PM_{10} average for the Southwest. Data are reported every sixth day.

The urban excess PM_{10} (AIRS-IMPROVE) for the Southwest is given in Figure 6-48, and the urban excess is substantially larger than in the regions discussed previously.

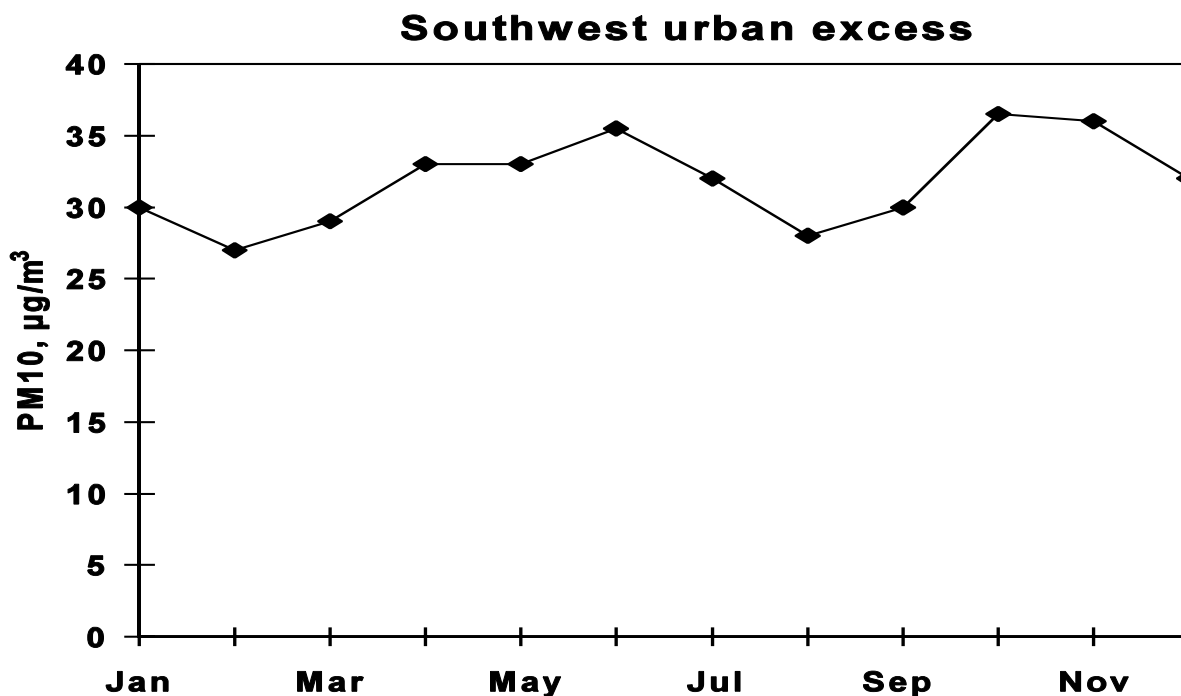


Figure 6-48. Urban excess concentration (AIRS minus IMPROVE) for the Southwest.

6.4.6 Regional Aerosol Pattern in the Northwest

The Northwest is defined to cover the bulk of the western United States north of the Arizona border (Figure 6-49a). It is covered by mountainous terrain of the Rockies, as well as the Sierra-Cascade mountain ranges. The Northwest is actually a collection of many aerosol subregions. The meteorology is highly variable between the Pacific Northwest and the Rocky Mountains with prevailing winds generally from the west. The main feature of the Northwest is pronounced elevation ranges between mountain tops and valleys, and the resulting consequences on emission pattern (confined to the valleys) and limited ventilation. The Northwest has also industrial population centers, such as Seattle, Portland, Salt Lake City and Denver.

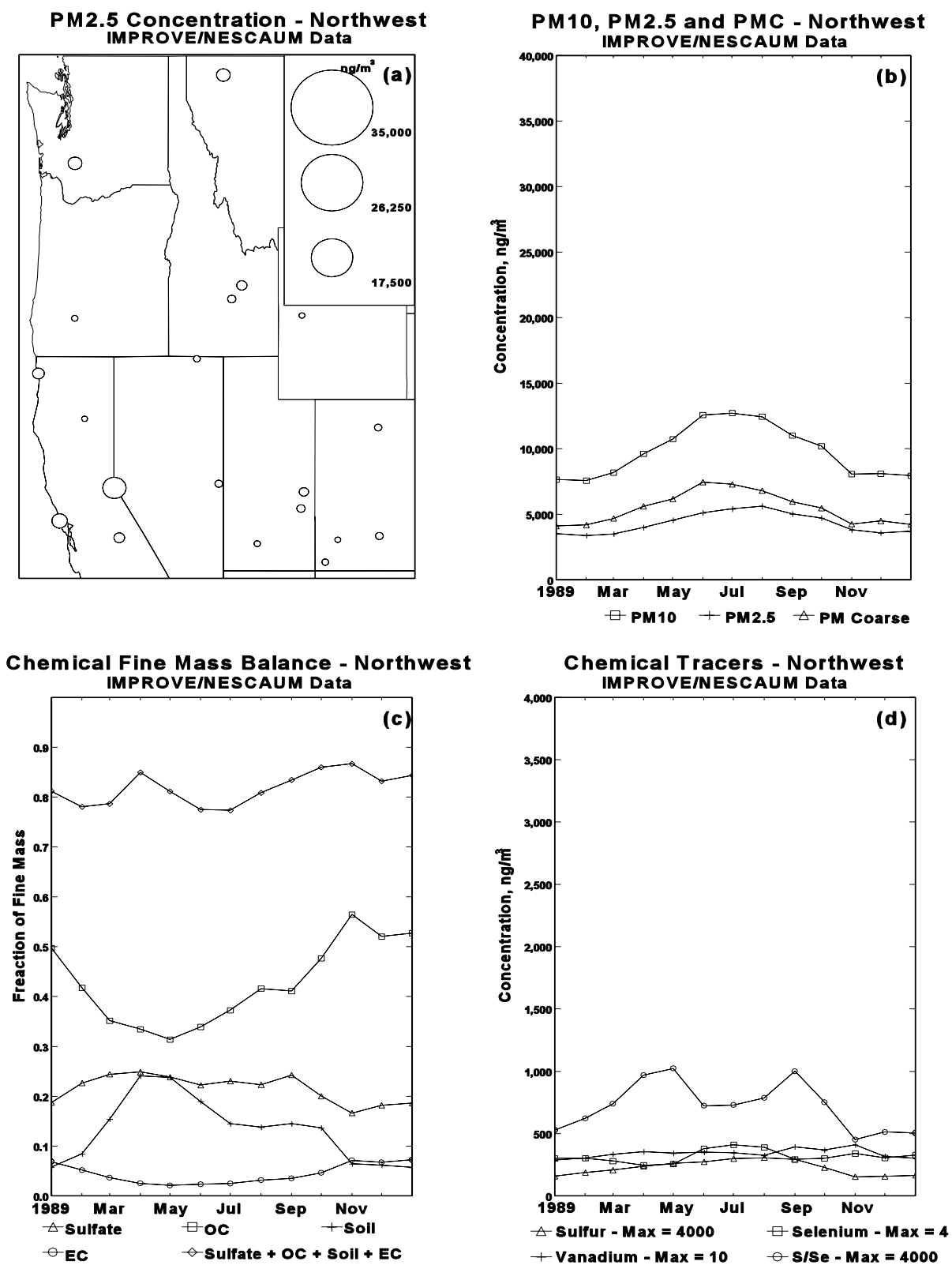


Figure 6-49. IMPROVE/NESCAUM concentration data for the Northwest:
 (a) monitoring locations; (b) PM₁₀, PM_{2.5}, and PMCoarse (PMC); (c) sulfate, soil, organic carbon (OC), and elemental carbon (EC) fractions; and (d) tracers.

6.4.6.1 Nonurban Size and Chemical Composition in the Northwest

The nonurban PM₁₀ concentrations show low values ranging between 7 to 14 $\mu\text{g}/\text{m}^3$ in the northwestern U.S. The seasonality shows a peak in the summer which is contributed by both fine and coarse particles. Coarse particles account for more than half of the PM₁₀, particularly during March through June spring season (Figure 6-49b).

The chemical mass balance (Figure 6-49c) shows roughly comparable contributions from sulfates and organics, but their seasonality is phase shifted. Sulfates prevail during the spring season while organics dominate during late fall (October through January). Fine particle soil dust contributes 20% during April and May, but decline well below 10% during the winter months (November through February). Overall, about 80% of the fine mass is accounted for by the sulfates, organic carbon, soil, and elemental carbon.

Examining the carbonaceous particles and regional haze in the western and northwestern U.S., White and Macias (1989) concluded that in the rural areas the concentrations of particulate carbon are comparable to those of sulfate. Examining particulate nitrate, White and Macias (1987) showed that the particulate nitrate concentration in the northern states (MT, ID, WY) were substantially higher than sulfate concentrations. Aerosol particulate nitrates over rural mountainous West were also episodic (i.e., few samples contributed a large fraction of the fine particle integrated dosage).

Both selenium and vanadium concentrations (Figure 6-49d) are low in the Northwest, but there is an indication of a summer peak of Se. The S/Se ratio is between 500 to 1,000, which is the lowest among the regions. This ratio has both spring peak as well as fall peak, similar to the pattern observed for the southwestern United States.

6.4.6.2 Urban Aerosols in the Northwest

In the northwestern U.S. there was a decrease in the annual average PM₁₀ concentration between 1988 and 1994 from 33 $\mu\text{g}/\text{m}^3$ to 24 $\mu\text{g}/\text{m}^3$ for all sites and from 35 $\mu\text{g}/\text{m}^3$ to 27 $\mu\text{g}/\text{m}^3$ for trend sites (Figure 6-50b). The reductions were 27% for all sites and 23% for trend sites. However, the 1985 to 1994 reductions may be overestimates because of the low station density in the early years. Once again, the average 1993 concentration is 25 $\mu\text{g}/\text{m}^3$ which is comparable to the 1993 concentrations of the eastern U.S. regions. The spread of

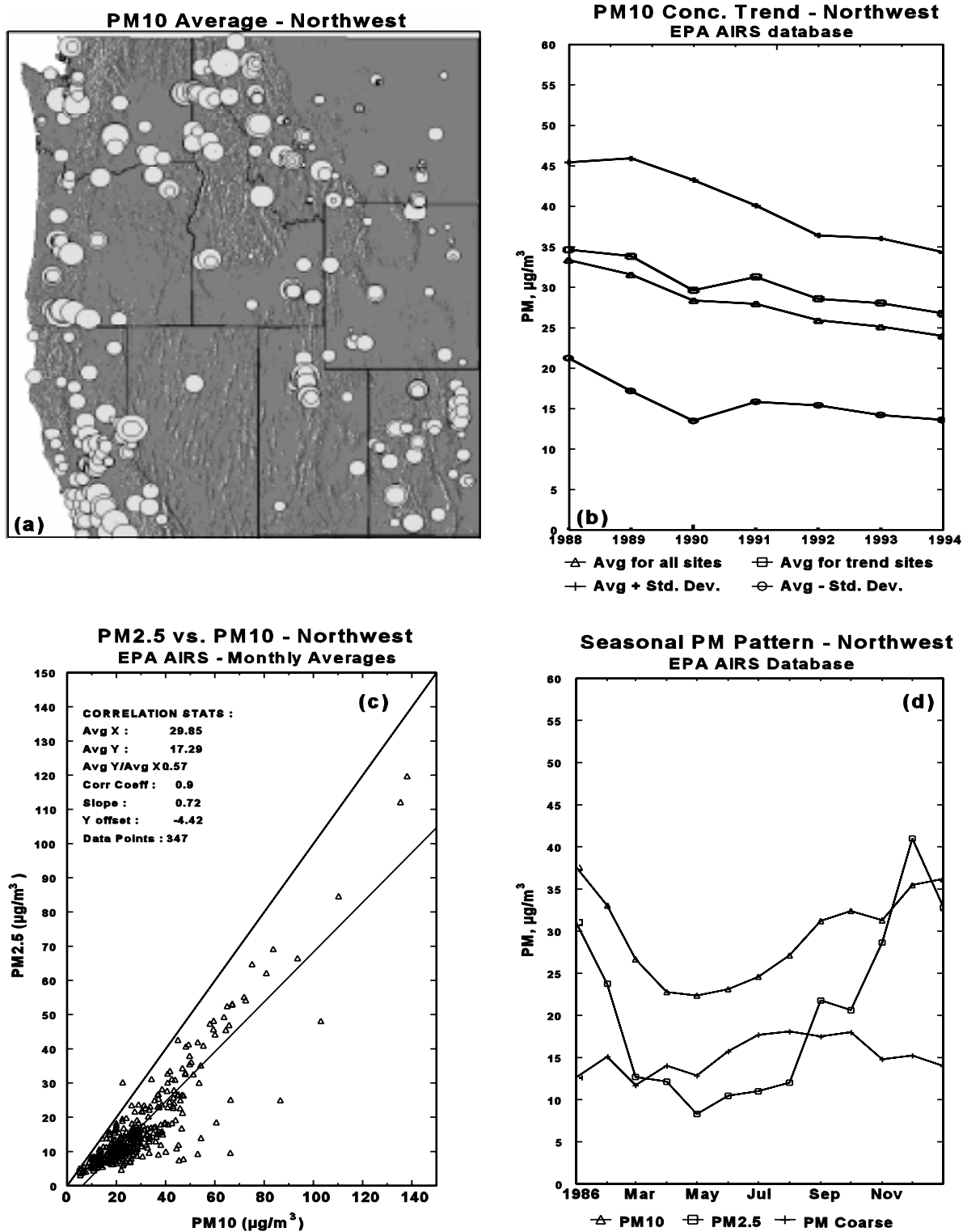


Figure 6-50. AIRS concentration data for the Northwest: (a) monitoring locations; (b) regional PM_{10} monitoring; (c) PM_{10} and $PM_{2.5}$ relationship; and (d) PM_{10} , $PM_{2.5}$, and PM_{Coarse} seasonal trend.

concentration among the Northwest stations is large, with standard deviation of 45% (Figure 6-50b). This spread in the concentration values is also evident from the various circle sizes of the Northwest map (Figure 6-50a). The highest PM_{10} concentrations in the Northwest occur in more remote mountainous valleys, rather than in the center of urban-industrial areas.

The seasonality of the northwestern United States has an amplitude of 36% which is comparable to the strong seasonality of the eastern U.S. The peak PM_{10} concentrations occur in the winter. The lowest PM_{10} concentration occurs during March through May and gradually increases to a peak in December through January, falling sharply between January and March.

The limited $PM_{2.5}$ - PM_{10} data for the Northwest indicate that on the average 57% of PM_{10} particles are $PM_{2.5}$. Figure 6-50c also indicates that the extreme PM_{10} concentrations are contributed mainly by fine particles. Furthermore, the extreme PM_{10} concentrations also occur in the winter season.

The daily concentration when averaged over the large and heterogeneous northwestern region exhibits a remarkably small sixth day to sixth day variation (Figure 6-51). Furthermore, there is clear seasonality with a strong winter peak. Within a given season, the regionally averaged concentrations only vary by 20 to 40% from one sixth day to another. Examination of the logarithmic standard deviation (Figure 6-50b) shows that the Northwest is spatially the most heterogeneous and has the highest logarithmic standard deviation among all regions. Evidently, in the Northwest high concentration PM_{10} pockets in topographically confined airsheds result in strong spatial and temporal variations. However, large scale elevated PM_{10} concentrations that cover the entire Northwestern region do not exist because high concentrations are not “synchronized” among the different airsheds. In this sense, the Northwest differs markedly from the eastern U.S., where large regional scale air masses with elevated PM_{10} determine the regionally averaged values. The urban excess PM_{10} (AIRS-IMPROVE) for the Northwest is given in Figure 6-52. The winter urban excesses are almost as large as in the Southwest (Figure 6-48). However, if the region is a collection of aerosol subregions, the small number of nonurban sites may not be representative of this collection of subregions.

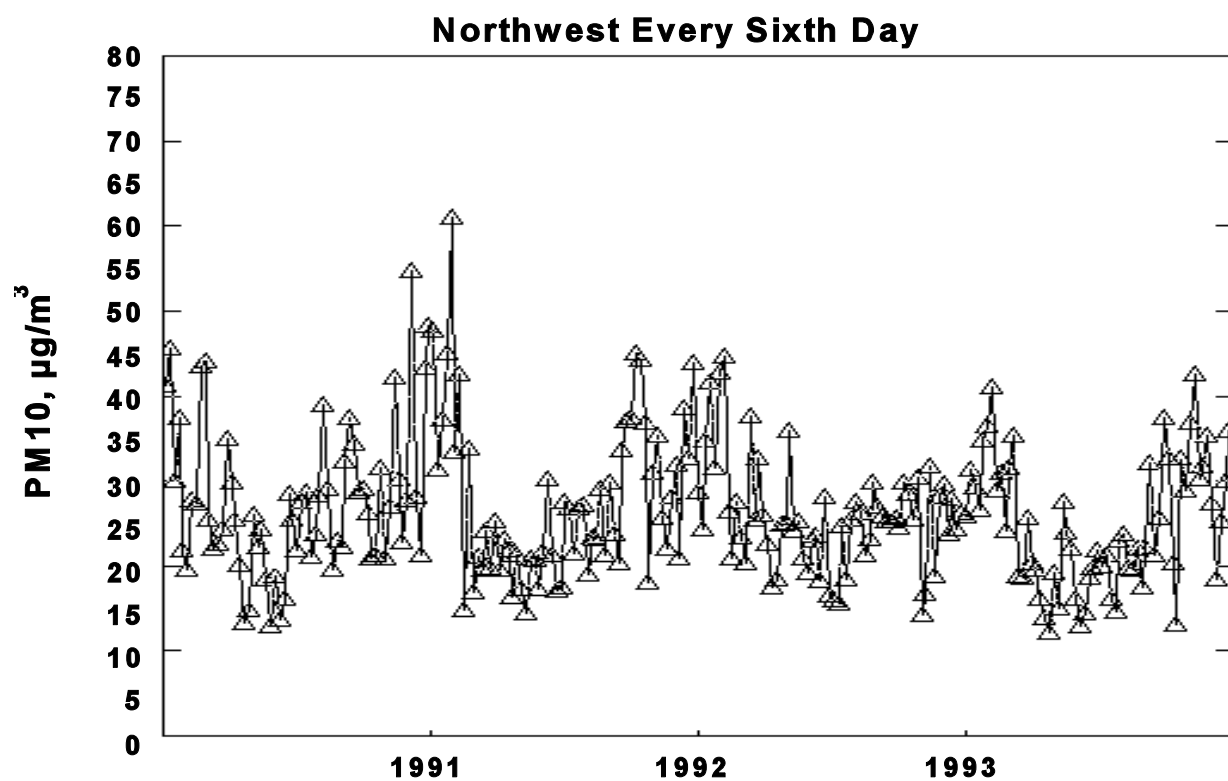


Figure 6-51. Short-term variation of PM₁₀ average for the Northwest. Data are reported every sixth day.

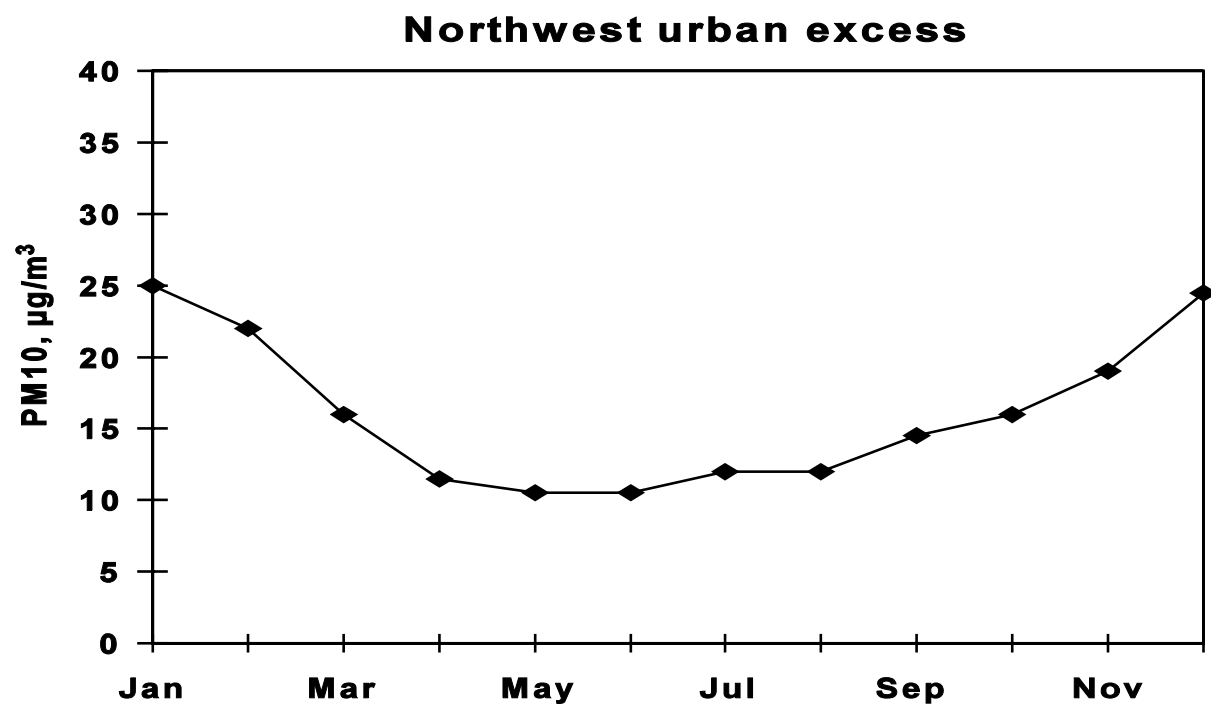


Figure 6-52. Urban excess concentration (AIRS minus IMPROVE) for the Northwest.

6.4.7 Regional Aerosol Pattern in Southern California

The region covers California south of San Francisco Bay (Figure 6-53a). It was considered as a separate region primarily because of the known high aerosol concentrations in the Los Angeles and San Joaquin basins. Meteorologically the region is exposed to the air flows from the Pacific that provide the main regional ventilation toward the south and southeast. The precipitation in the region occurs in the winter season, with the summer being hot and dry. The regional ventilation of the San Joaquin Valley is severely restricted by the Sierra Nevada Mountain range. Also, the San Gabriel Mountains constitute an air flow barrier east of the Los Angeles basin. Both basins have high population, as well as industrial and agricultural activities. Hence, human activities are believed to be the main aerosol sources of the region.

6.4.7.1 Nonurban Size and Chemical Composition in Southern California

The PM_{10} concentration at the few nonurban sites over southern California ranges between $10 \mu\text{g}/\text{m}^3$ during December through February, and 20 to $25 \mu\text{g}/\text{m}^3$ in April through October. Coarse particles contribute more than 50% of the PM_{10} during the warm season May through October. Both the fine and coarse aerosol fractions are lowest during the winter months (December through March). The summer peak fine particle seasonality at nonurban southern California sites is in marked contrast to the strongly fall peaked urban fine particle concentrations (Figures 6-53b, 6-54d).

The chemical mass balance (Figure 6-53c) of nonurban southern California aerosol has a substantial contribution by organics of 30 to 40% throughout the year. Sulfates account for only 10 to 15% of the fine mass in the winter, and about 20% in the summer months. The sulfate fraction of the nonurban southern California fine mass is the lowest among the regions. Fine particle soil dust is about 10% between April through November and drops to 5% during the winter months. A notable feature of the southern California chemical mass balance is that 45% of the winter, and 35% of the summer fine mass concentration is not accounted by sulfates, soils, organic carbon, and elemental carbon. Nitrates are a major contributor to the southern California aerosols (Solomon et al., 1989).

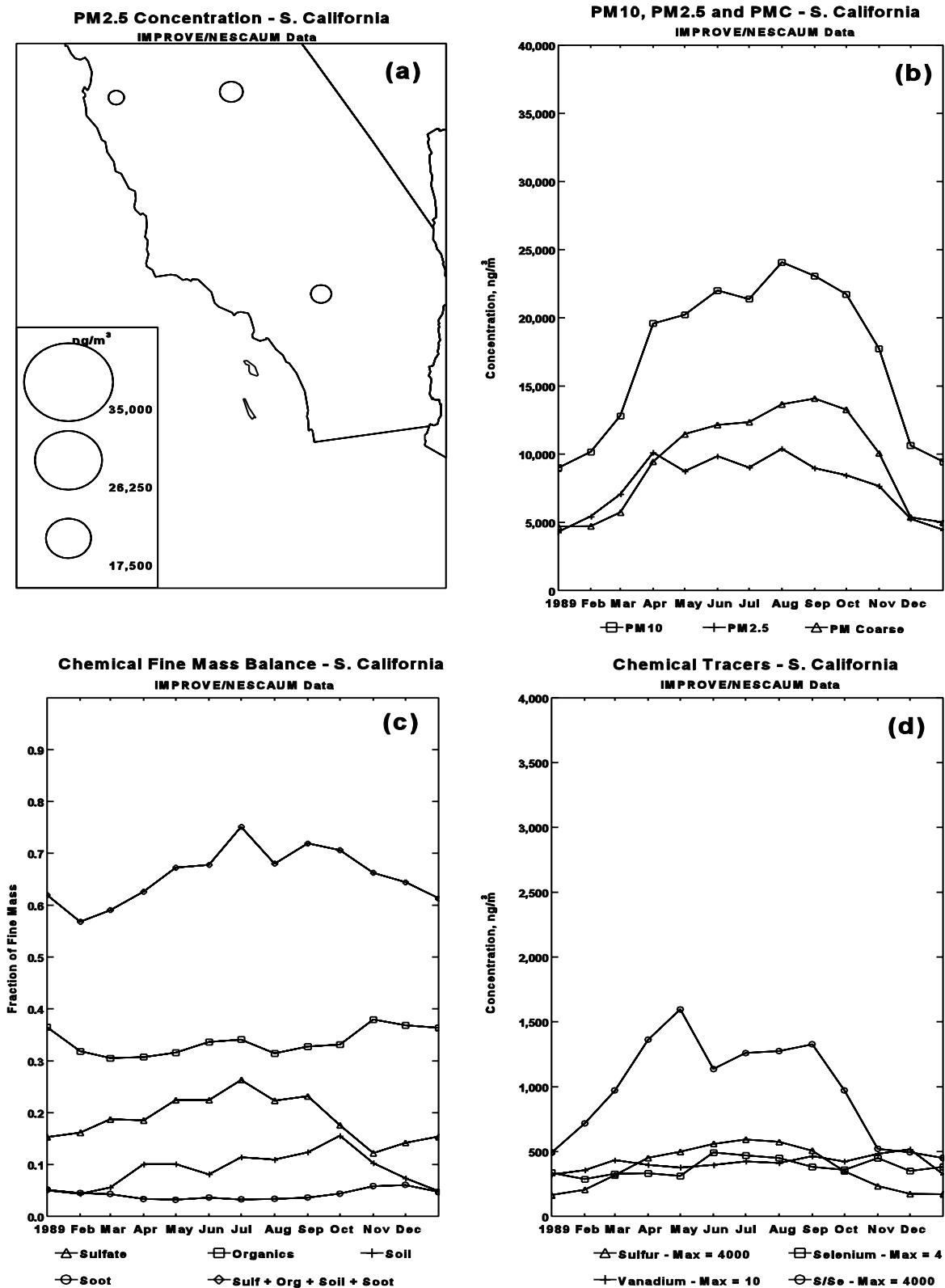


Figure 6-53. IMPROVE/NESCAUM concentration for Southern California:
 (a) monitoring locations; (b) PM₁₀, PM_{2.5}, and PM Coarse (PMC); (c) sulfate, soil, organic carbon (OC), and elemental carbon (EC) fractions; and (d) tracers.

Both selenium and vanadium (Figure 6-53d) show low values throughout the year without significant seasonality. On the other hand the fine particle sulfur concentration shows a definite summer peak at 500 ng/m^3 , compared to 200 ng/m^3 during the winter. Consequently, the S/Se ratio increase from 500 in the winter 1,000 to 1,500 in the summer.

6.4.7.2 Urban Aerosols in Southern California

In the southern California region there was a decrease in the annual average PM_{10} concentration between 1988 and 1994 from $41 \text{ } \mu\text{g/m}^3$ to $30 \text{ } \mu\text{g/m}^3$ for all sites and from $42 \text{ } \mu\text{g/m}^3$ to $32 \text{ } \mu\text{g/m}^3$ for trend sites (Figure 6-54b). The reductions were 27% for all sites and 24% for trend sites. There is a sizable concentration spread among the stations (40% standard deviation). Inspection of the circle sizes in the map points (Figure 6-54a) to uniformly high concentrations in the San Joaquin Valley as well as in the Los Angeles basin. The low concentration sites are located either on the Pacific coast outside of the Los Angeles basin or in the Sierra Nevada Mountains. Thus there are clear patterns of basin-wide elevated PM_{10} concentrations with lower values in more remote areas (Figure 6-54a).

The seasonality of the PM_{10} pattern in southern California is significant at 27%. Furthermore, the seasonal pattern is unique that the highest concentrations occur in November and the lowest in March. However, it is a see saw rather than a sinusoidal pattern.

On the average, about half of southern California PM_{10} is contributed by fine particles as shown in the $\text{PM}_{2.5}$ - PM_{10} scattergram. Most of the high PM_{10} concentration months dominated by fine particles tend to be in the fall.

The sixth day average time series for the southern California region (Figure 6-55) shows remarkably high sixth daily variance, between 10 and $75 \text{ } \mu\text{g/m}^3$. The lowest values tend to occur between January and April, while the highest concentrations ($>50 \text{ } \mu\text{g/m}^3$) tend to occur during October through December. Concentration excursions of a factor of two are common between two consecutive six day time periods. However, visual inspection of the sixth daily signal also reveals a substantial seasonality highest in the fall (September through December) and lowest in the spring.

The urban excess PM_{10} (AIRS-IMPROVE) for Southern California is given in Figure 6-56. The urban excesses are larger especially in winter, as are the urban excesses

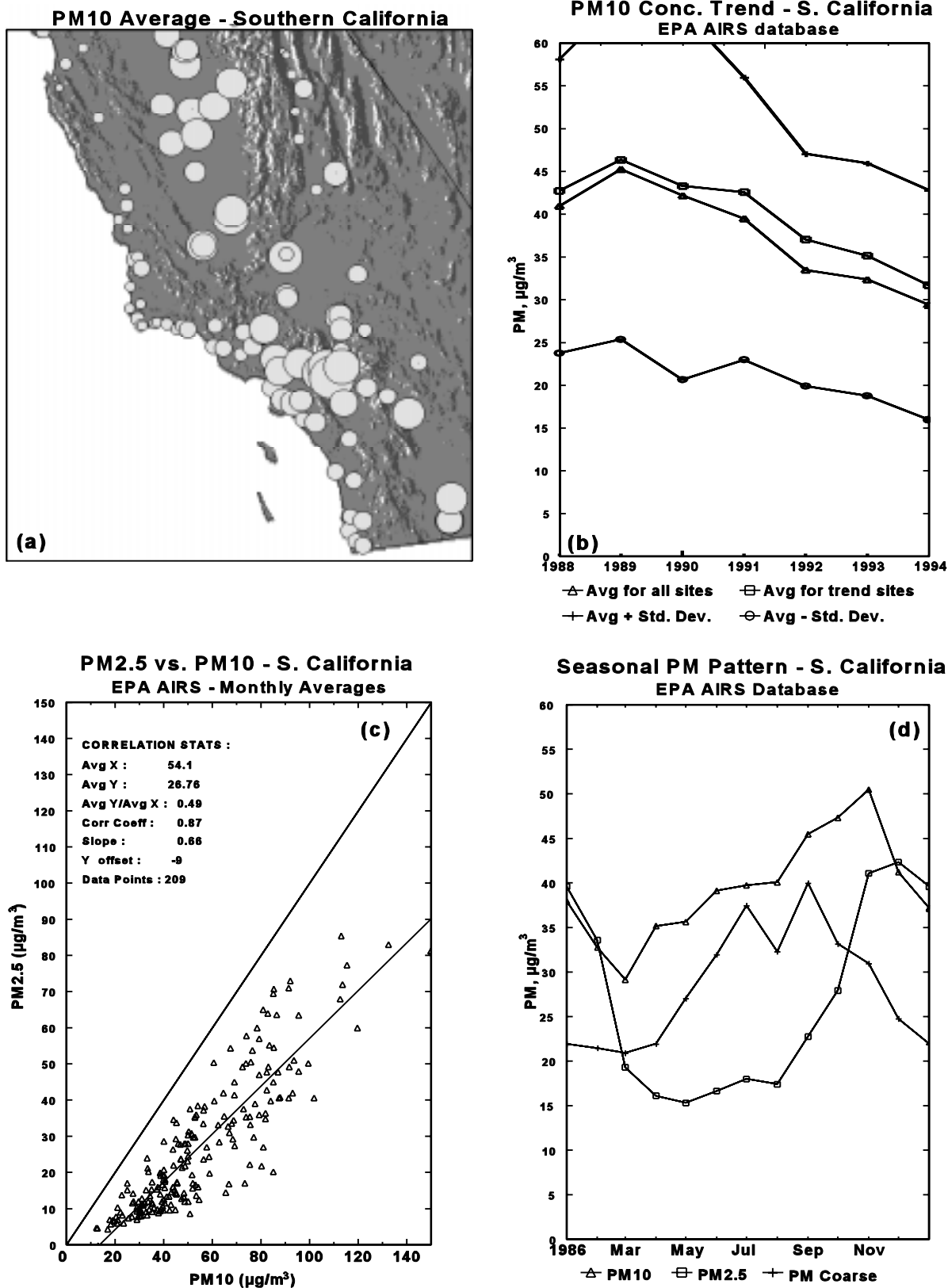


Figure 6-54. AIRS concentrations for Southern California: (a) monitoring locations; (b) regional PM_{10} monitoring trends; (c) PM_{10} and $\text{PM}_{2.5}$ relationship; and (d) PM_{10} , $\text{PM}_{2.5}$, and $\text{PM}_{\text{Coarse}}$ seasonal trend.

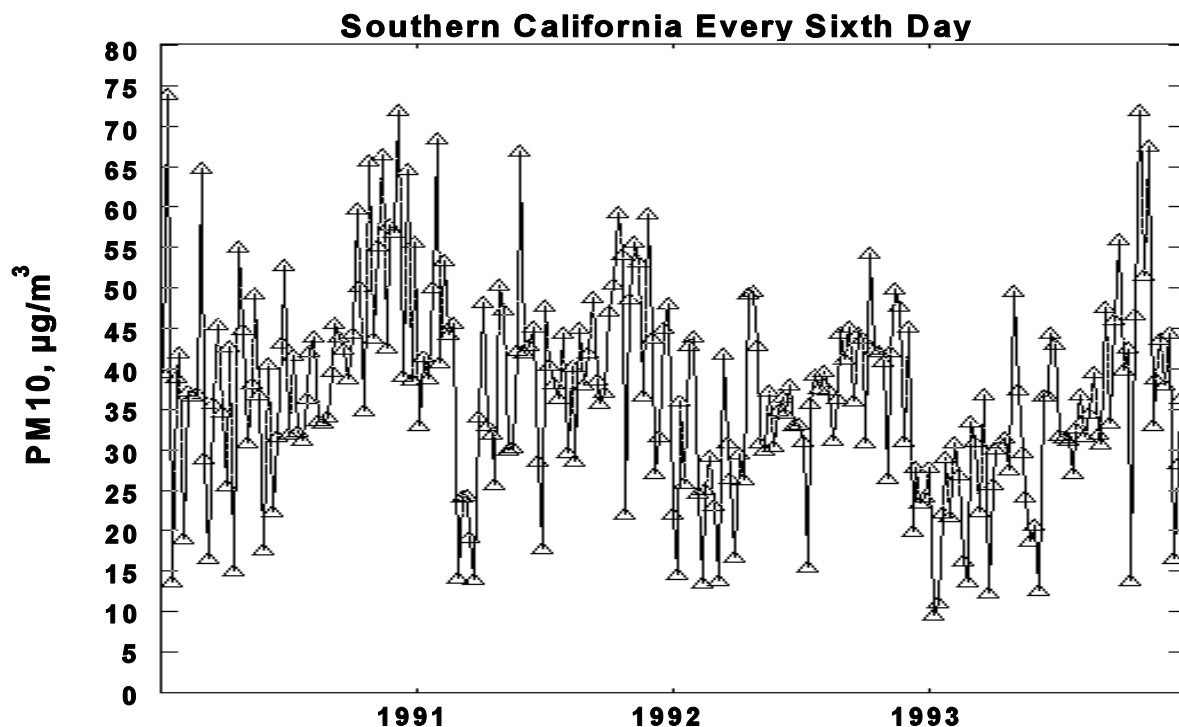


Figure 6-55. Short-term variation of PM₁₀ average for Southern California. Data are reported every sixth day.

in the Northwest. Again, these results depend on measurements from a small number of

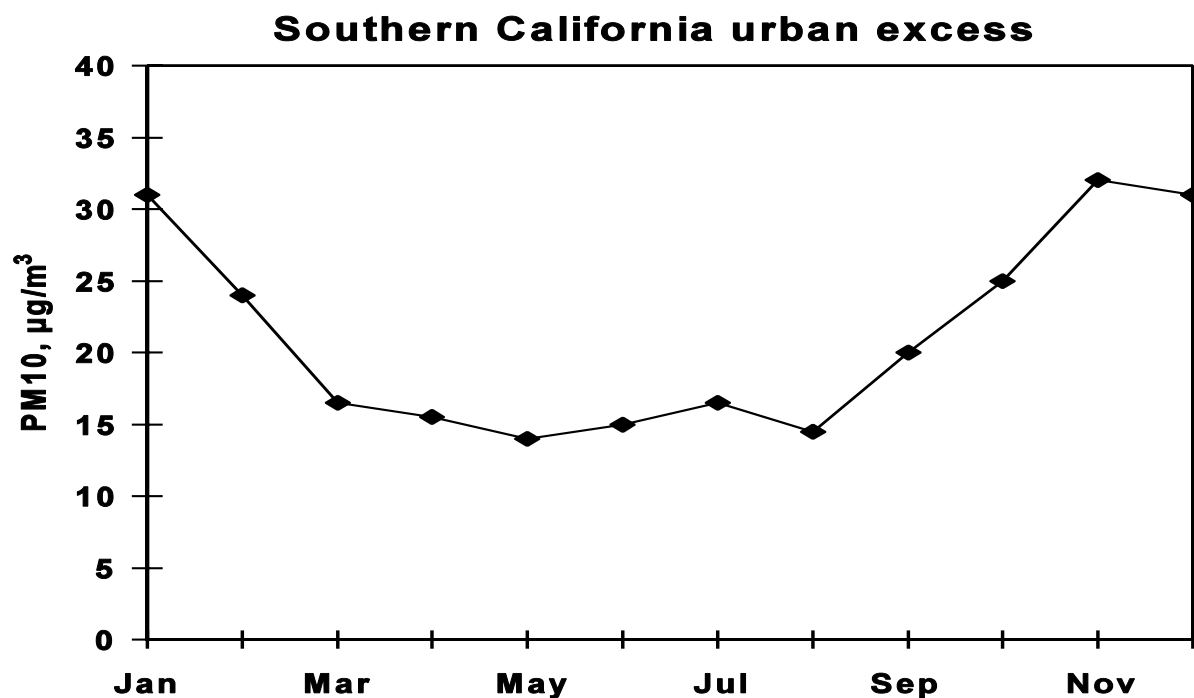


Figure 6-56. Urban excess concentration (AIRS minus IMPROVE) for Southern California.

nonurban sites.

6.5 SUBREGIONAL AEROSOL PATTERNS AND TRENDS

The health and other effects of aerosols are imposed on individuals, and the density of population varies greatly in space. Consequently, the evaluation of effects requires the knowledge of aerosol concentrations over specific locations where sensitive receptors reside. The purpose of this section is to characterize the aerosol pattern at specific sites, small airsheds or subregions. The discussions is organized by region and then by monitoring site within a region. Most urban aerosol sampling is confined to PM_{10} or in some instances to $PM_{2.5}$ and PM_{Coarse} . However, detailed chemical composition data are reviewed for several urban areas.

6.5.1 Subregional Aerosol Pattern in the Northeast

In the northeastern region, the Shenandoah National Park and Washington, DC constitute a useful urban-nonurban set of size and chemically resolved aerosol data. New York City and Philadelphia are also major metropolitan areas with substantial aerosol data bases. Whiteface Mountain site distinguishes itself from its background by high elevation.

6.5.1.1 Shenandoah National Park

The PM_{10} concentration at the Shenandoah National Park IMPROVE site (Figure 6-57a) exhibits a pronounced summer peak ($27 \mu\text{g}/\text{m}^3$), which is a factor of three higher than the winter value of $9 \mu\text{g}/\text{m}^3$. The strong seasonality is driven by the seasonal modulation of the fine mass which accounts for 70 to 80% of the PM_{10} mass (Figure 6-57a). The coarse particle concentration ranges between 3 and $6 \mu\text{g}/\text{m}^3$, which is small compared to the fine particle mass, particularly in the summer season, when it accounts for $< 25\%$ of the PM_{10} . It is clear that at this nonurban site, in the vicinity of industrial source regions, fine particles determine the magnitude of PM_{10} .

The chemical mass balance for the Shenandoah IMPROVE monitoring site (Figure 6-57b) clearly documents the dominance of sulfate aerosols, which contribute about